

# Quantum mechanical retrocausation? Call for nonlocal causal models!

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## **Abstract**

A new possible version of multisimultaneous causality is proposed, and real experiments allowing us to decide between this view and quantum mechanical retrocausation are further discussed. The interest of testing quantum mechanics against as many nonlocal causal models as possible is stressed.

*Keywords:* superposition principle, retrocausation, superluminal nonlocality, multisimultaneous causality.

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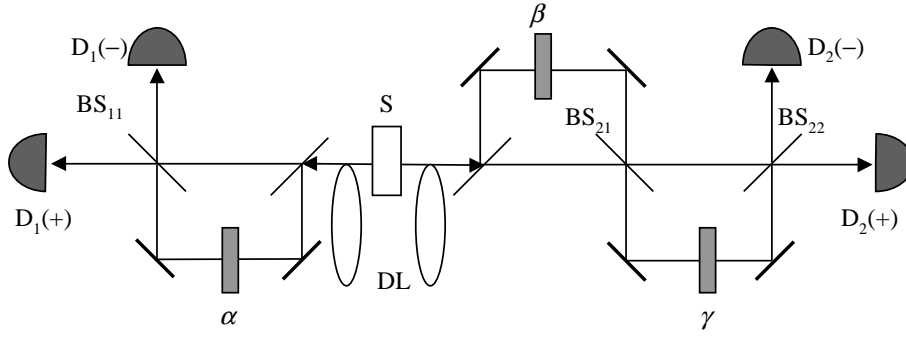


Figure 1: Impact series experiment with photon pairs: photon 2 impacts successively on beam-splitter  $BS_{21}$  and  $BS_{22}$ . See text for detailed description.

In a recent paper [1] we have proposed an impact series experiment and argued the quantum mechanical superposition principle to be at odds with the causality principle. We show in this paper that the causal model used in [1] is not the only possible, and discuss further real measurements that may allow us to decide between quantum mechanical retrocausation and multisimultaneous causality.

Consider again the setup sketched in Fig.1. Photon pairs are emitted through down-conversion from a source  $S$ . Photon 1 enters the left hand side interferometer and impacts on beam-splitter  $BS_{11}$  before being detected in either  $D_1(+)$  or  $D_1(-)$ , while photon 2 enters the 2-interferometer series on the right hand side impacting successively on  $BS_{21}$  and  $BS_{22}$  before being detected in either  $D_2(+)$  or  $D_2(-)$ . Each interferometer consists in a long arm of length  $L$ , and a short one of length  $l$ . We assume as usual the path difference set to a value which largely exceeds the coherence length of the photon pair light, but which is still smaller than the coherence length of the pump laser light.

For a pair of photons, eight possible path pairs lead to detection. We label them as follows:  $(l, ll)$ ;  $(L, ll)$ ;  $(l, Ll)$  and so on; where, e.g.,  $(l, Ll)$  indicates the path pair in which photon 1 has taken the short arm, and photon 2 has taken first the long arm, then the short one.

Ordinary Quantum Mechanics assumes indistinguishability to be a sufficient condition for observing quantum interferences and entanglement, whereas Relativistic Nonlocality or Multisimultaneity assumes this condition to be only a necessary one. In any case, as a first step we must distribute all possible paths in mutually distinguishable subensembles. The following table gives the four mutually distinguishable subensembles of the ensemble of all possible path pairs.

$$\begin{array}{ll}
 (l, LL) & : 2L - l \\
 (L, LL), (l, Ll), (l, lL) & : L \\
 (l, ll), (L, Ll), (L, lL) & : l \\
 (L, ll) & : 2l - L
 \end{array} \tag{1}$$

where the right-hand side of the table indicates the path difference between the single paths of each photon characterizing each subensemble of path pairs. From now on, unless stated otherwise, we consider only those events that are characterized by path difference  $L$ , i.e.,

$(L, LL), (l, Ll), (l, lL)$ . Experimentally, this is done by appropriate coincidence electronics [4]. By means of delay lines DL different time orderings in the laboratory frame can be arranged.

The conventional application of the superposition principle yields the following values for the conventional joint probabilities:

$$\begin{aligned}
P_{++}^{QM} &= \frac{1}{12} [3 - 2\cos(\alpha + \beta) - 2\cos(\alpha + \gamma) + 2\cos(\gamma - \beta)] \\
P_{+-}^{QM} &= \frac{1}{12} [3 - 2\cos(\alpha + \beta) + 2\cos(\alpha + \gamma) - 2\cos(\gamma - \beta)] \\
P_{-+}^{QM} &= \frac{1}{12} [3 + 2\cos(\alpha + \beta) + 2\cos(\alpha + \gamma) + 2\cos(\gamma - \beta)] \\
P_{--}^{QM} &= \frac{1}{12} [3 + 2\cos(\alpha + \beta) - 2\cos(\alpha + \gamma) - 2\cos(\gamma - \beta)], \tag{2}
\end{aligned}$$

and the corresponding single probabilities for the detections at side 1 (left-hand side) of the setup:

$$\begin{aligned}
P_{+\pm}^{QM} &\equiv P_{++}^{QM} + P_{+-}^{QM} = \frac{1}{2} - \frac{1}{3} \cos(\alpha + \beta) \\
P_{-\pm}^{QM} &\equiv P_{-+}^{QM} + P_{--}^{QM} = \frac{1}{2} + \frac{1}{3} \cos(\alpha + \beta) \tag{3}
\end{aligned}$$

and at side 2 (right-hand side):

$$\begin{aligned}
P_{\pm+}^{QM} &\equiv P_{++}^{QM} + P_{-+}^{QM} = \frac{1}{2} + \frac{1}{3} \cos(\beta - \gamma) \\
P_{\pm-}^{QM} &\equiv P_{+-}^{QM} + P_{--}^{QM} = \frac{1}{2} - \frac{1}{3} \cos(\beta - \gamma) \tag{4}
\end{aligned}$$

Consider now a multisimultaneous causal model working according to the following rules:

1. Half of the pairs traveling by  $(L, LL)$  produce outcomes at  $BS_{11}$  and  $BS_{22}$  according to superposition with  $(l, lL)$ , and half according to superposition with  $(l, Ll)$ .
2. Half of the pairs traveling by  $(l, lL)$  produce outcomes at  $BS_{11}$  and  $BS_{22}$  according to superposition with  $(L, LL)$ , and half according to superposition with  $(l, Ll)$ .
3. Half of the pairs traveling by  $(l, Ll)$  produce outcomes at  $BS_{11}$  and  $BS_{22}$  according to superposition with  $(L, LL)$ , and half according to superposition with  $(l, lL)$ .

This model yields the following joint probabilities:

$$\begin{aligned}
P_{++}^{MC} &= \frac{1}{12} [3 - \cos(\alpha + \beta) - \cos(\alpha + \gamma) + \cos(\gamma - \beta)] \\
P_{+-}^{MC} &= \frac{1}{12} [3 - \cos(\alpha + \beta) + \cos(\alpha + \gamma) - \cos(\gamma - \beta)] \\
P_{-+}^{MC} &= \frac{1}{12} [3 + \cos(\alpha + \beta) + \cos(\alpha + \gamma) + \cos(\gamma - \beta)] \\
P_{--}^{MC} &= \frac{1}{12} [3 + \cos(\alpha + \beta) - \cos(\alpha + \gamma) - \cos(\gamma - \beta)],
\end{aligned} \tag{5}$$

and the corresponding single probabilities for the left-hand side:

$$\begin{aligned}
P_{+\pm}^{MC} &= \frac{1}{2} - \frac{1}{6} \cos(\alpha + \beta) \\
P_{-\pm}^{MC} &= \frac{1}{2} + \frac{1}{6} \cos(\alpha + \beta)
\end{aligned} \tag{6}$$

and for the right-hand side:

$$\begin{aligned}
P_{\pm+}^{QM} &= \frac{1}{2} + \frac{1}{6} \cos(\beta - \gamma) \\
P_{\pm-}^{QM} &= \frac{1}{2} - \frac{1}{6} \cos(\beta - \gamma)
\end{aligned} \tag{7}$$

Therefore, regarding detections in side 1 the multisimultaneous causal model proposed in this paper conflicts less with quantum mechanics than the model proposed in [1]. On the contrary, whereas the model in [1] did fit with quantum mechanics for detections at side 2, the model proposed here conflicts. This clearly supports the retrocausal interpretation of quantum mechanics for orderings in which the impacts on BS<sub>22</sub> lie time-like separated after the impacts on BS<sub>11</sub>. Anyway quantum mechanics seems to exclude any causal explanation.

Again, a real experiment can be carried out with the same arrangement proposed in [1], i.e., modifying the setup used in [5] in order that the photon traveling the long fiber impacts on a second beam-splitter before it is getting detected. For the values:

$$\begin{aligned}
\alpha + \beta &= n\pi, \\
\beta - \gamma &= n\pi,
\end{aligned} \tag{8}$$

with  $n$  integer, the equations (3) and (6) yield the predictions:

$$\begin{aligned}
E^{QM} &= |P_{+\pm}^{QM} - P_{-\pm}^{QM}| = \frac{2}{3}, \\
E^{MC} &= |P_{+\pm}^{MC} - P_{-\pm}^{MC}| = \frac{1}{3},
\end{aligned} \tag{9}$$

the equations (4) and (7) the predictions:

$$\begin{aligned}
E^{QM} &= |P_{\pm+}^{QM} - P_{\pm-}^{QM}| = \frac{2}{3}, \\
E^{MC} &= |P_{\pm+}^{MC} - P_{\pm-}^{MC}| = \frac{1}{3},
\end{aligned} \tag{10}$$

and the equations (2) and (5) the joint probabilities predictions:

$$\begin{aligned}
E^{QM} &= \sum_{\sigma, \omega} (-\sigma\omega) P_{\sigma\omega}^{QM} = \frac{2}{3}, \\
E^{MC} &= \sum_{\sigma, \omega} (-\sigma\omega) P_{\sigma\omega}^{MC} = \frac{1}{3}.
\end{aligned} \tag{11}$$

Hence, for settings according to (8) the experiment represented in Fig. 1 allow us again to decide between quantum mechanics and the multisimultaneous causal model proposed above, through determining the corresponding experimental quantities from the four measured coincidence counts  $R_{\sigma\omega}$  in the detectors.

Before concluding we would like to point out briefly some of the possible ramifications the different multisimultaneous causal models may have. In the type of impact series experiments described in [2], the multisimultaneous causal model proposed in [1] works according to the quantum mechanical superposition principle for certain time orderings of the impacts on the beam-splitters, but permits to arrange 2 *non-before* events with devices at rest in the laboratory frame and, consequently, conflicts also in this case with quantum mechanics. On the contrary the multisimultaneous causal model proposed in this paper works according to the superposition principle only for experiments without successive *non-before* impacts, and is insensitive to time orderings with beam-splitters at rest. However it is much more sensitive to time orderings appearing with fast moving beam-splitters, and may bear plenty of calculation patterns as those referred to in [3].

In conclusion: Impact series experiments seem to offer a new road to test Quantum Mechanics against Multisimultaneity with devices at rest. Since results upholding Quantum Mechanics would strong speak in favor of retrocausation, impact series experiments could become with relation to causality what Bell experiments are with relation to local realism. In the alternative case, the experiments will allow us to decide which multisimultaneous model fits better the way Nature behaves. Quantum Mechanics is undoubtedly a pretty well experimentally confirmed theory, but the questionable nonlocality of single probabilities revealed by impact series deserves undoubtedly further testing. To this aim it may be useful to see whether other suitable nonlocal causal models are still possible, and to study further the implications of those already proposed.

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